

Atmospheric temperature coherent variations effects, preceding strong earthquakes

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Abstract. We analyzed satellite measurements of temperature at upper troposphere/lower stratosphere (UTLS) levels separated by the tropopause above the epicentral area of a strong earthquake with a magnitude of $M=7.3$ in the Northern Tien-Shan (Kyrgyzstan) that took place on August 19, 1992. The developed algorithm and method of continuous wavelet transform allowed detecting of abnormal behavior, temporal, spatial and spectral coherence of short-period temperature variations, preceding the seismic event. The results show that the spatial structure and dynamics of temperature anomalies in the area of UTLS have a sufficiently stable relation to seismic activity.

1 Introduction

Progress in development and improvement of satellite technologies, as well as availability of a large number of specialized services and databases predetermined extensive use remote sensing results for purposes of research of the interaction between various geophysical processes and seismic monitoring in particular. An important task of anomalies identification in temperature time series (spatial images), together with selection of parameters, that may serve as potential attributes of strong earthquakes preparation, is selection and application of the most effective methods of processing of experimental data. A lot of methods and algorithms for selection of anomalies for various data types that describe processes occurring in time and preceding earthquakes, from simple methods of visual interpretation to more complex methods based on wavelet transform and conjoint application of wavelets and neural networks [1] have been developed. The most widely spread method of detection and localization of deviation of corresponding parameters from typical behavior is the RST (Robust Satellite Techniques) data analysis [2, 3].

Within researches of atmospheric effects conditioned by strong earthquake impacts an important physical characteristic, that describes dynamics and state of the atmosphere, is temperature. The task of selection of pre-seismic attributes of anomalous behavior in temperature time series may be solved on the basis of application of relevant algorithms [3–5] and the wavelet-analysis methodology with account for differences in frequency properties of spectra of anomalous temperature perturbations at upper troposphere/lower stratosphere levels separated by the tropopause (UTLS). The algorithm developed by the authors and

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based on general principles of the universal RST method in combination with spectral and correlation analysis is intended for selection of short-period spectral constituents with consequent analysis of not only abnormality degree of amplitude but specifics of change in the phase and temporary realm, which are simultaneously observed at two UTLS levels divided by the tropopause. The output parameter of the algorithm, changes of which were compared to seismic activity, was integrated index of anomalous variations ($D_{\delta T}$), that actually served as the measure of coherence or conformity of temperature variations at two isobaric level in time and space.

In this research we present results of revealing of temporal, spatial and spectral coherence in UTLS temperature variations over the epicentral area of a strong earthquake of magnitude of $M=7.3$ that occurred in Kyrgyzstan on August 19, 1992.

2 Seismic and temperature measurements data

On August 19, 1992 at 02:04:37 (UTC) a strong earthquake with a magnitude of $M=7.3$ occurred at the depth of ~ 27 km in the Northern Tien-Shan (42.142°N ; 73.575°E) when intense activation of the seismic process started [6]. A map of the aftershock field of the Suisamyr earthquake is presented in Fig. 1a. 20 aftershock of magnitude 3.8–6.3 were registered during the day. Fig. 1b shows a histogram of distribution of the total daily energy (E_s) of regional seismic events registered in Kyrgyz Seismic Network (KNET) seismological network in August 1992. Sharp activation of seismic intensity was decreasing to background values at the end of 1993.

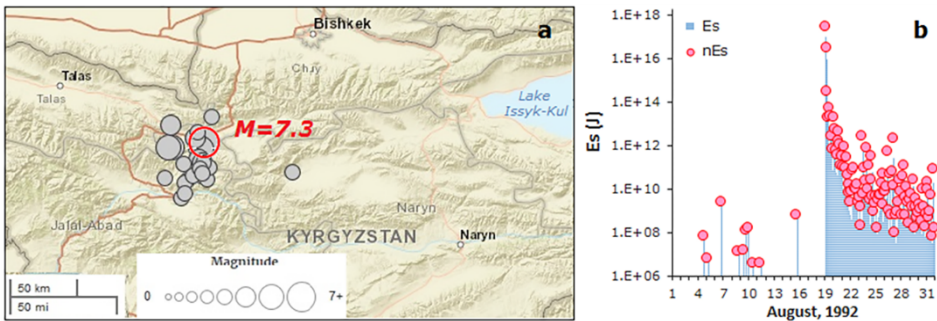


Fig. 1. The aftershock field of the earthquake of $M=7.3$ (Northern Tien-Shan) 19.08.1992 (a) and distribution of the total daily energy (E_s) of regional seismic events in August 1992, (b)

Analysis of altitude and temporal variations of atmospheric temperature was performed using satellite measurement data. Temperature data of the MERRA-2 [7] reanalysis system are based on satellite observations processed in a global model and represent synthesized temperature values at standard isobaric levels from 450 to 70 hPa with spatial resolution of $0.5^{\circ} \times 0.625^{\circ}$. An advantage of reanalysis is higher time discretization, that is $\Delta t=3\text{h}$, which allowed to detail the process of temperature perturbations formation.

3 Results and discussions

3.1 Temporal and spatial temperature perturbations

Given that the earthquake under consideration belongs to special events in the regional seismicity and is the strongest one ($M=7.3$) in the territory of Tien-Shan over the last 30 years, the whole annual cycle (1992) of temperature variations in the tropopause has been analyzed. Changes in semidiurnal temperature variations at isobaric levels from 300 hPa to

100 hPa in 1992 (Fig. 2a) were of complex nature and presented a seasonal trend modulated by various short-period components. Diagnostics results of temperature anomalies at the levels separated by the 300 hPa and 100 hPa tropopause using the algorithm described in [3, 5] demonstrated a well-defined values outburst of $D_{\delta T} = 2.5$ parameter several days before the seismic event of $M=7.3$ (Fig. 2b), that allows to assume some relation with the earthquake preparation period (Fig. 2c).

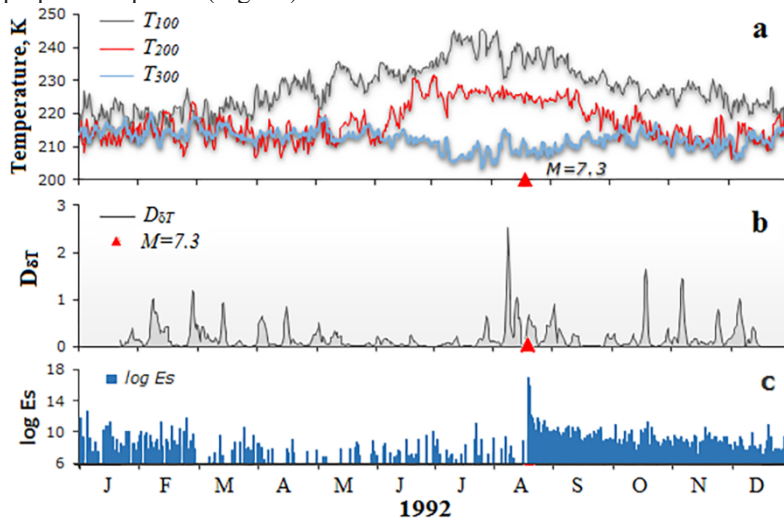


Fig. 2. Temperature variations at the 300, 200 and 100 hPa isobaric levels (a), changes of anomalous variations integral parameter $D_{\delta T}$ (b) and distribution of the log of radiated seismic energy ($\log Es$) (c) in 1992

Changes of spatial distribution of $D_{\delta T}$ integral parameter, describing of the process of perturbations formation in the tropopause during preparation and occurrence of the strong earthquake on December 18–19, 1992 are presented in Fig. 3.

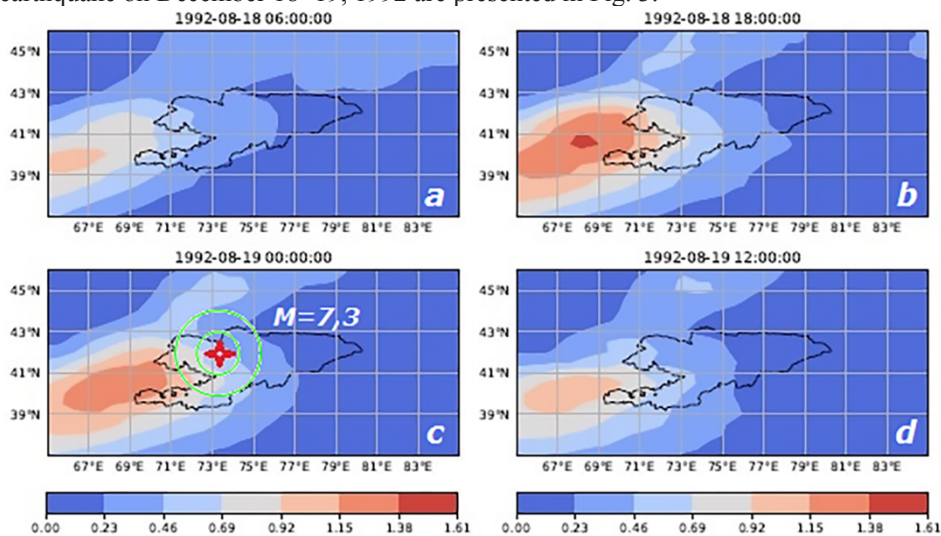


Fig. 3. Evolution of $D_{\delta T}$ integral parameter spatial distribution during the preparation and occurrence of the earthquake of $M=7.3$ (August 19, 1992, 02:04:36). The maximum of anomalous perturbation was observed ~ 8 h before the event

Location of the high values of $D_{\delta T}$ parameter remained unchanged for 2 days and the anomaly maximum was observed ~ 8 hours before the seismic event of $M=7.3$ (Fig. 3b).

As for the mechanism of formation of anomalous temperature perturbations preceding major earthquakes, we hold to an assumption that wave processes, i.e. effects of excitement of intense gravitational waves, in particular, long-period seismic-gravitational oscillations, play the main role in lithosphere-atmosphere interaction. Increase in intensity of oscillation of large local volumes of the Earth's crust in the process of development of strong earthquakes results in synchronous and spectrum-identical atmospheric pulsations, the recurrence rate of which is $\sim 6-8$ days [8].

An illustration of changes of altitude distribution and characteristic wavelengths of temperature perturbations is transformation of wave manifestations in vertical profiles (Fig. 4a, b) and respective temperature anomalies in wavelet spectra before and after the earthquake (August 18 and 21, 1992, 03:00 UTC). The altitude range from 5.0 km to 60.0–65.0 km was considered. The most intense harmonics preceded the seismic event and were observed in the UTLS. The main contribution to temperature variations was made by oscillations with vertical wavelength $\lambda_z=11.0-12.0$ km (Fig. 4c). After the earthquake, temperature vertical distribution represented a more complex combination of two wavelengths (~ 6.0 km and 18.0 km). The most intense wave perturbations ($\lambda_z=15.0-20.0$ km) moved to the stratopause (Fig. 4d).

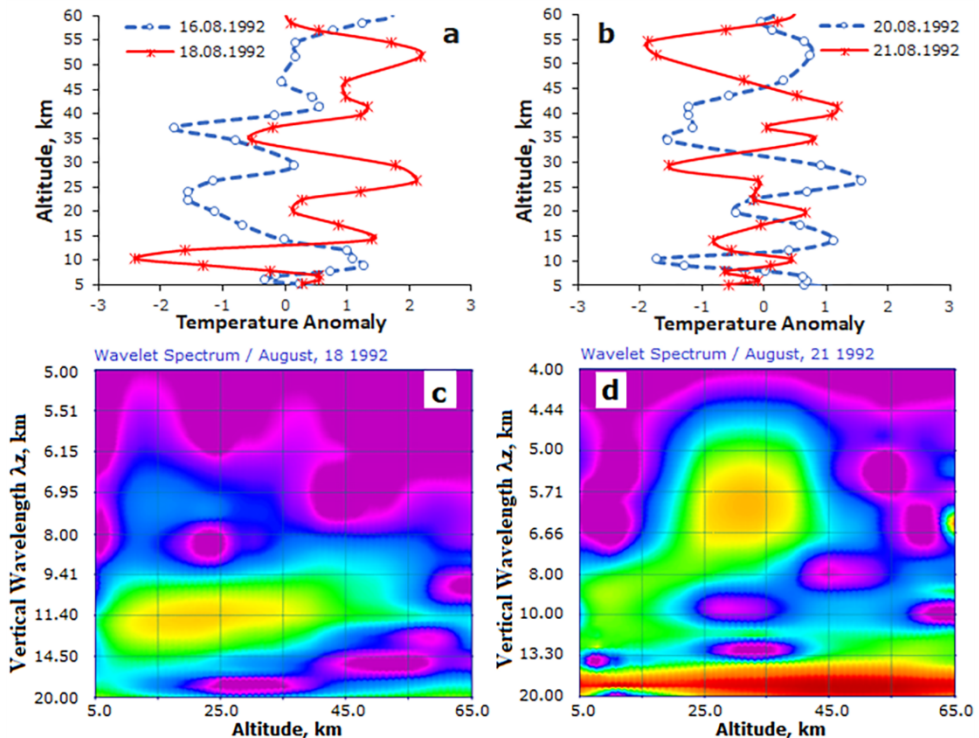


Fig. 4. Transformation of vertical temperature profiles and temperature anomalies wavelet spectra before and after the earthquake ($M=7.3$): (a) and (c) – August 18, 1992; (b) and (d) – August 21, 1992

3.2 Spectral coherence estimates of temperature variations

Analysis of dynamics of periodicities of satellite data analyzed was performed using continuous wavelet transform. Wavelet spectrograms of temperature time series at 300 hPA

and 100 hPa levels (Fig. 5), built for the range of periods from 0.125 to 64 days, demonstrate change in frequency properties during the whole annual cycle under consideration. Specifics of the presented spectrograms are well-defined intensive oscillations within the range of periods of 4–12 days in first decades of August. Whereas, there wasn't any simultaneously appearing at both isobaric levels and equally significant temperature perturbation in the dynamics of variation spectrum in 1992.

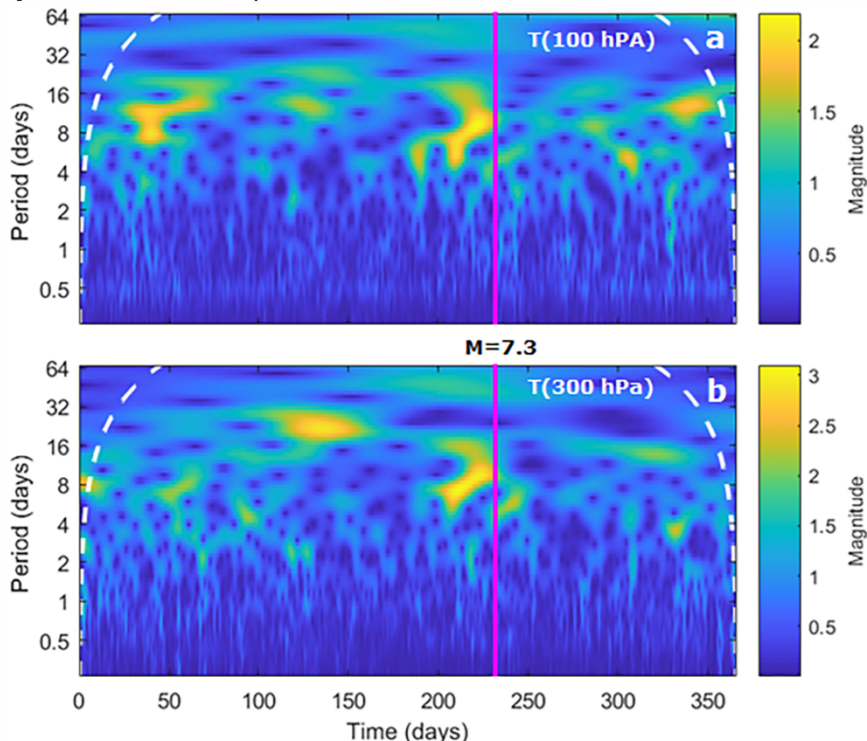


Fig. 5. Dynamics of temperature variations spectra at the 300 and 100 hPa levels in 1992

To analyze consistent variability and statistic interrelation between temperature variations in atmosphere layers divided by the tropopause above the epicentral area of an earthquake calculation of the spectral measure of temperature was performed (Fig. 6).

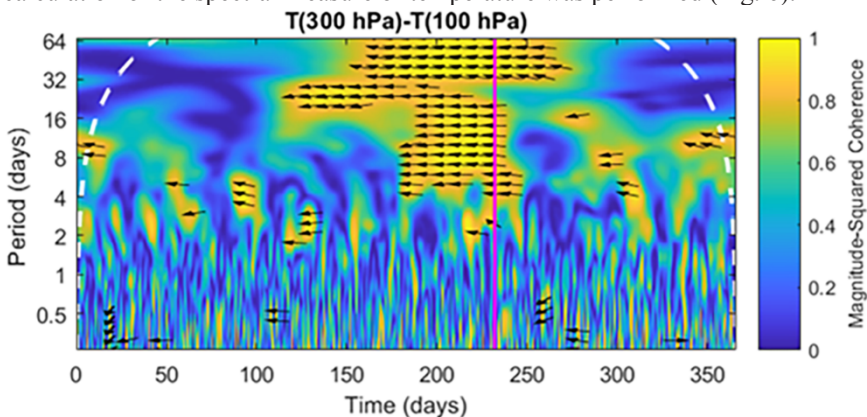


Fig. 6. The square of coherence between coefficients of wavelet transform of temperature of two time series at isobaric levels of 300 and 100 hPa in 1992. The vertical line is the moment of the earthquake of $M=7.3$

Temporal changes of coherence between coefficients of wavelet transform of temperature at isobaric levels of 300 hPa and 100 hPa presented in the diagram characterize correlations, that exist between individual spectral components.

The effect of strong coherence of temperature at the atmosphere levels under consideration preceded the strong earthquake and became apparent in the range of periods of 4–12 days. Thereat, the seismic-atmospheric effect of a strong earthquake was more distinctly apparent in high-frequency components of the spectrum, the period of which was from 4 to 6 days. Duration of anomalous increase of coherence was substantially longer for levels located close to the tropopause. Arrows directions are indicative of phase opposition of oscillations under observation. Therefore, occurrence of anomalous temperature perturbations is in line with the time of coherent behavior manifestation, and the highlighted range of periods, where the effect is most distinctly observed, coincides with experimentally obtained assessments of most informative spectral components, that we used in calculations of integral indicators [4].

4 Conclusion

Results of analysis of satellite remote sensing data showed that anomalous temperature changes in the tropopause were observed above the epicentral area of the strong earthquake of $M=7.3$. Study of periodicities dynamics revealed effects of coherent temperature behavior in the UTLS in the interval of periods from 4 to 6 days preceding activation of the seismic regime in the territory of the Northern Tien Shan. The presented spatial-temporal distributions of anomalous temperature perturbations point at probable relation to the seismic process. We observed differences in vertical distribution of temperature variations frequency characteristics before and after the earthquake.

On the basis of the results obtained it can be assumed that for the purpose of research of seismic-atmospheric effects of strong earthquakes, along with visualization of development of spatial distribution of the anomalous variations of integral parameter, generation of maps reflecting dynamics of temperature variations in short-period spectra, evolution of vertical wave lengths and density of potential energy of gravitational waves in the troposphere and stratosphere may be promising.

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